

Advances in Limnogeology and Paleolimnology

**with a special focus on corroborated chronologies
using paleomagnetic secular variations**

Habilitationsschrift

vorgelegt am 29. Mai 2015

der Chemisch-Geowissenschaftlichen Fakultät
der Friedrich-Schiller-Universität Jena

von

Dr. rer. nat. Torsten Haberzettl

aus Coburg

Gutachter:

1. Prof. Dr. Roland Mäusbacher, Friedrich-Schiller-Universität Jena
2. PD Dr. Peter Frenzel, Friedrich-Schiller-Universität Jena
3. Prof. Dr. Frank Schäbitz, Universität zu Köln

Erteilung der Lehrbefähigung am 16.12.2015

Table of contents

Table of contents	3
Acknowledgments	4
Abstract	5
Zusammenfassung	6
The use of lacustrine sediments for paleoenvironmental reconstructions	7
Dating sediments	10
Paleomagnetism and magnetostratigraphy	11
Magnetic susceptibility	12
Paleomagnetic secular variation (PSV) stratigraphy	15
Multi-dating-approach	19
Conclusions and Outlook	20
Outline and structure of the thesis	24
References	31
Appendix (Papers)	
Curriculum Vitae	
Selbstständigkeitserklärung	

Acknowledgements

I am indebted to many people. There are 140 excellent co-authors who greatly contributed to the publications listed in this thesis and helped me to finish it. Of course any weaknesses or inaccuracies of this work are in my sole responsibility. Since I would probably forget one or the other person in these acknowledgements I do not want to tick names here and hence let it be.

Nevertheless, I do want to thank my supervisors, my colleagues, the technicians, secretaries, student helpers, students, and friends at the Friedrich Schiller University Jena, the Institut des sciences de la mer de Rimouski, the University of Göttingen, the University of Bremen, and collaborating institutes around the world. Without their help and the support of various funding agencies from different countries it would have been impossible to finish this thesis.

Finally, I would like to thank my family which was not always exited when I left for expeditions or other scientific duties but always supported me in every way!

Thank you so much!

Abstract

Scientific investigations on lakes started during the 19th century in Europe and the United States. Since this time paleolimnological and limnogeological investigations increased distinctly and during the last few years there has been a rapid advance in the understanding of processes operating in lacustrine systems. However, most studies focused on easily accessible locations. Despite major improvements in scientific knowledge of lakes up to now, there still remain gaps especially for the areas investigated in this thesis, i.e., the different rainfall zones of South Africa, the Tibetan Plateau, the steppe parts of Argentinean Patagonia, the eastern Ecuadorian Andes, and the Island of Sulawesi (Indonesia). The papers in this thesis try to close some of these gaps and try to contribute to a better understanding of processes that occurred in the past and their (paleo-)environmental consequences in regions that have rarely been investigated so far. The aim of this thesis is to provide new paleolimnological and limnogeological information and develop process based conceptual models from areas of the world where this kind of information is very scarce to inexistent. A special emphasis will be on the construction of reliable chronologies using multi-dating approaches. In this context one focus will be on the evaluation of chronologies using paleomagnetic secular variations wherever this was possible depending on sediment properties.

In order to reach this aim the papers forming this thesis are structured as follows:

1. New conceptual approaches
2. Paleoenvironmental reconstructions using simple magnetostratigraphically not confirmed chronologies since no paleomagnetic secular variation data could be obtained from the sediment and other paleolimnological and limnogeological investigations
3. Paleomagnetic investigations and/or magnetostratigraphic evaluations of chronologies
4. Paleoenvironmental information from magnetostratigraphically corroborated chronologies
5. Other dating approaches

Zusammenfassung

Erste wissenschaftliche Untersuchungen an Seen begannen im 19. Jahrhundert in Europa und den USA. Seitdem hat die Zahl der paläolimnologischen und limnogeologischen Untersuchungen deutlich zugenommen. Während der letzten Jahre verbesserte sich so zunehmend das Verständnis für Prozesse, die in lakustrinen Systemen ablaufen. Allerdings konzentrierten sich die meisten Studien auf leicht zugängliche Regionen. Trotz deutlicher wissenschaftlicher Fortschritte, gibt es deshalb noch immer Lücken auf dem Gebiet der Seenforschung, vor allem in den schwieriger zugänglichen Gegenden, die in dieser Arbeit untersucht werden. Dies sind die verschiedenen Regenzone Südafrikas, das Tibetische Plateau, der argentinische Teil der patagonischen Steppe, die östlichen Anden Ecuadors und die Insel Sulawesi in Indonesien. Die Beiträge in dieser Arbeit versuchen einige dieser Lücken zu schließen. Weiterhin versuchen sie, zu einem besseren Verständnis von Prozessen, die in der Vergangenheit abgelaufen sind, und deren Konsequenzen für die (Paläo-)Umwelt welche bisher in nur unzureichendem Maße untersucht wurden, beizutragen. Ziel dieser Arbeit ist es zum einen, neue paläolimnologische und limnogeologische Informationen zu sammeln. Zum anderen sollen in Gegenden, aus denen es bisher nur wenige Informationen gibt, neue prozessorientierte Ansätze entwickelt werden. Ein Fokus wird auf die Erstellung verlässlicher Chronologien mit Hilfe eines Multiplen-Datierungs-Ansatzes gelegt. Der Schwerpunkt liegt dabei auf der Evaluierung von Altersmodellen mit Hilfe von paläomagnetischen Säkularvariationen. Um dieses Ziel zu erreichen, sind die in dieser Arbeit enthaltenen Beiträge wie folgt strukturiert:

1. Neue konzeptionelle Ansätze
2. Paläoumweltrekonstruktionen basierend auf einfachen, nicht magnetostratigraphisch abgesicherten Altersmodellen, da keine Extraktion von paläomagnetischen Säkularvariationen aus diesen Sedimenten möglich war, sowie andere paläolimnologische und limnogeologische Untersuchungen
3. Paläomagnetische Untersuchungen und/oder magnetostratigraphische Evaluierungen von Altersmodellen
4. Paläoumweltrekonstruktionen basierend auf magnetostratigraphisch abgesicherten Altersmodellen
5. Andere Datierungsansätze

The use of lacustrine sediments for paleoenvironmental reconstructions

The currently occurring climate change with its consequences such as rising temperatures or sea level as reported by the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (Masson-Delmotte *et al.* 2013; Stocker *et al.* 2013) has major impacts on modern societies and will impose increased stress on many regions of the world (Last 2002; Haberzettl *et al.* 2014, Appendix 12). Global warming can for example affect human health (Franchini & Mannucci 2015) and climate change is going to alter ecosystems (Scholze *et al.* 2006; Warszawski *et al.* 2013) and considerably exacerbate water scarcity in different parts of the world (Schewe *et al.* 2014). In order to predict future climatic developments, sophisticated models are required which need to be calibrated and evaluated (Bradley & Eddy 1991; Smol 2008). Unfortunately, measured climatic and environmental data for this purpose for western Europe are only available since the late 17th or early 18th century (Jones & Bradley 1995). On a global scale data only go back to the mid-19th century (Stocker *et al.* 2013). Apart from this, instrumental and observational datasets are very sparse or suffer from an insufficient quality (Smol 2008). Hence, they provide an inadequate perspective on climate variability and the evolution and history of climate (Bradley 1999). In addition to that, the period covered by instrumental data is already intensively influenced by an anthropogenic impact in many regions of the world and many climatic and environmental changes occurred far back in time before observation was possible (Birks & Birks 2006). The only option to overcome this issue of short time series of measured data and anthropogenic impact is the use of natural geoarchives from less anthropogenically influenced areas for paleoenvironmental reconstructions (Bradley & Eddy 1991; Haberzettl 2006; Zolitschka *et al.* 2006). Paleoclimate reconstructions from such geoarchives can distinctly extend the climatic records further back in time and allow current variations in, for example, sea level or climate (including extreme events like droughts and floods) to be placed in a broader perspective of (paleo-) environmental change (Stocker *et al.* 2013). Reconstructions may also allow to unravel driving factors and mechanisms for climatic changes. If these causes are understood

it is possible to forecast climatic variations for the future (Bradley & Eddy 1991; Bradley 1999).

Paleoclimate archives also record slowly occurring climate transitions and system feedbacks (Stocker *et al.* 2013) which due to their long duration are not contained in the short time series derived from instrumental measurements. This allows to assess whether recent changes are unusual or not (Masson-Delmotte *et al.* 2013). Although in a different context Winston Churchill was right when he said: “The farther backward you can look the farther forward you are likely to see”. This look back in time can be realized by analyses of geoarchives like for example speleothems, glaciers – or **lakes**.

Today, lakes form only about 1 % of the continental surface of the Earth (Collinson 1978), however, their geological significance is much greater than this percentage suggests (Talbot & Allen 1996). Lakes are remarkable features and their sediments can be used for paleoenvironmental reconstruction in terms of space and time (Meybeck 1995; Verrecchia 2008). This is possible since lacustrine systems mostly continually respond to climatic conditions (Hostetler 1995) which is immediately stored in the sediments. For example climatically induced changes in precipitation and evaporation can induce fluctuations in lake levels (Hostetler 1995; Haberzettl *et al.* 2005; Haberzettl 2006; Anselmetti *et al.* 2009; Kasper *et al.* 2012, Appendix 15; Long *et al.* 2012, Appendix 22; Kasper *et al.* 2013, Appendix 16; Ohlendorf *et al.* 2013, Appendix 26; Doberschütz *et al.* 2014, Appendix 7; Kasper *et al.* 2015, Appendix 17) pointing to changes in the hydrological cycle.

Scientific investigations on lakes started during the second half of the 19th century in Switzerland (Last & Ginn 2005) focusing on bathymetry, temperature, modern lake level variations, or turbidity (Forel 1879-1880; Salis 1884; Forel 1887). Pioneering (limno-)geological investigations were also carried out in the European Alps (Forel 1885, 1887) and on Lake Lahontan (Russel 1885) or Pleistocene Lake Bonneville (Gilbert 1890) in the United States. However, for the upcoming almost 100 years only little attention was put on real limnogeological or paleolimnological aspects probably because the water has been a distinct barrier to recover the sediments in a useful way and there was hardly any text dealing solely with paleolimnology (Reeves 1968). Looking at textbooks in the 1980s sedimentological processes in lakes, if mentioned at all, were restricted to only a few pages (Håkanson & Jansson 1983) and

paleoclimatology in general was still in its infancy (Bradley 1999). Therefore, only a few decades ago, the status of lake sediment research was still described as the hole in a donut (Collinson 1978). Since this time limnogeological investigations increased distinctly. During the last few years there has been rapid advance in the understanding of processes operating in lacustrine systems and how these processes influence sedimentological records preserved in these systems (Bradley 1999; Last 2002; Last & Ginn 2005; Cabrera *et al.* 2009; Birks 2012). Today, paleoclimatology including paleolimnology is a major field in earth sciences (Bradley 1999). Probably no other continental archive has so much to offer for potential significant contributions to geosciences as lacustrine environments (Talbot & Allen 1996; Last 2002; Last & Ginn 2005). Consequently, lacustrine paleoenvironmental reconstructions can be seen as complementary to marine records (Cabrera *et al.* 2009) since they allow an environmental reconstruction to be performed directly in and from the region of interest. However, most lacustrine studies seem to have focused on easily accessible locations. Despite major improvements in scientific knowledge of lakes up to now there still remain gaps especially for the areas investigated in this thesis, e.g., South Africa (Meadows 2001; Holmgren *et al.* 2003; Haberzettl *et al.* 2014, Appendix 12), Patagonia (Argentina) (Anselmetti *et al.* 2009; Fey *et al.* 2009, Appendix 8), the Island of Sulawesi (Indonesia) (Kirleis *et al.* 2011; Wündsche *et al.* 2014, Appendix 33; Biagioni *et al.* 2015, Appendix 4), or the only marine archive investigated in this thesis, the epicontinental sea of the Hudson Bay including Hudson Strait (Haberzettl *et al.* 2010, Appendix 10). This thesis has to be seen in the context and as part of the rapidly progressing fields of limnogeology and paleolimnology. Most papers in this thesis contribute to a better understanding of processes that occurred in the past and their paleoenvironmental consequences in regions that have rarely been investigated so far. In this context, another focus of this thesis will be on the establishment of reliable chronologies by for example testing age-depth models using magnetostratigraphy on geologically seen very young sediments, i.e., <4 ka.

Dating sediments

For all paleoenvironmental studies accurate dating is of crucial importance (Bradley & Eddy 1991). Without an accurate chronology the determination of synchronicities, leads, or lags for certain climatic events or shifts is impossible (Bradley 1999). Dating is also essential if the speed and frequency at which past environmental changes occurred is of interest (Bradley & Eddy 1991; Bradley 1999). On short time scales and for recent sediments chronologies can be established using radioisotopic techniques such as ^{137}Cs or ^{210}Pb . For longer time scales ages are usually provided by (high-resolution) AMS radiocarbon dating, in an ideal case on determined fragile terrestrial plant material (Birks & Birks 2006) such as leaves which make a reworking of the material unlikely. Unfortunately, such kind of material is rare in many areas of the world as for example the Tibetan Plateau (Kasper *et al.* 2012, Appendix 15; Doberschütz *et al.* 2014, Appendix 7; Miehe *et al.* 2014, Appendix 24; Kasper *et al.* 2015, Appendix 17) or Patagonia (Fey *et al.* 2009, Appendix 8; Kastner *et al.* 2010, Appendix 18). In most cases the only solution in such areas is the application of radiocarbon dating on aquatic plant remains or bulk sediment samples if only radiocarbon dating is available to establish a chronology (Niemann *et al.* 2009, Appendix 25; Haberzettl *et al.* 2013, Appendix 11; Reinwarth *et al.* 2013, Appendix 29). Often such chronologies suffer from a hard water effect which has been overcome by various approaches like for example subtracting the age of the sediment water interface from each individual radiocarbon age (Kasper *et al.* 2012, Appendix 15). However, even today in some cases imprecise reservoir correction on the Tibetan Plateau leads to troubles in correlating records from different lacustrine archives. If this is the case this inhibits a final conclusion about regional synchronicities of climatic shifts in this area.

Often chronologies based on bulk sediment ages also contain many age reversals due to reworking of fine organic sediment. The only solution in this case is to use the youngest ages in stratigraphic order as maximum ages (Fig. 1). Although this is a very conservative approach, comparisons of climate reconstructions from these archives to reconstructions from nearby archives often reveal remarkable similarities (Wündsche *et al.* 2014, Appendix 33).

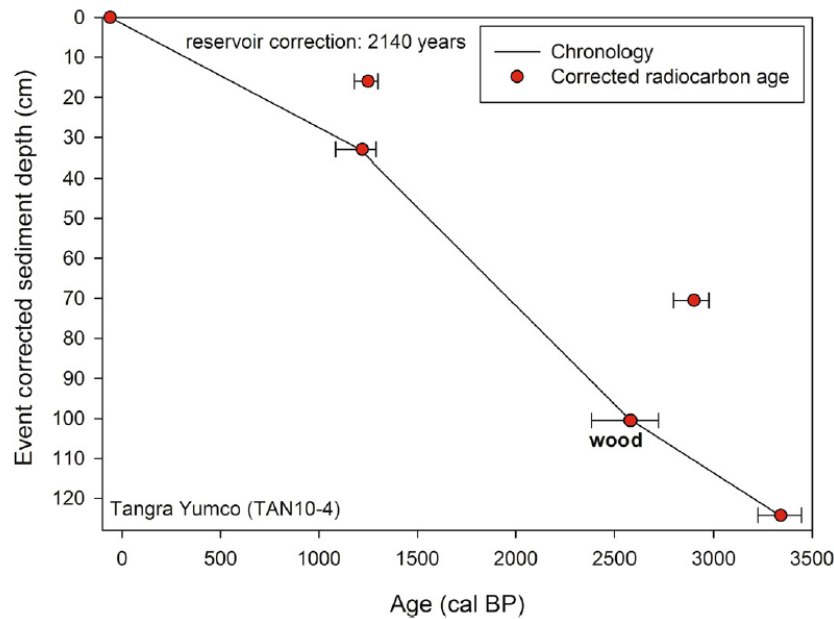


Fig. 1: Chronology of sediment core TAN10-4 from Lake Tangra Yumco (Tibet). In this case reservoir corrected bulk ages and an age of a piece of wood was used for age-depth modeling. The only solution to establish a chronology for records containing age reversals as it is the case here is to use the youngest ages in stratigraphic order as maximum ages (Haberzettl et al. 2015, Appendix 13, modified).

A major step forward in age-depth-modeling is the incorporation of independent time marker layers as for example macro or micro tephra (Lowe 2011) which can either be used to establish or confirm existing chronologies (Haberzettl et al. 2007; Haberzettl et al. 2009, Appendix 9). However, such layers are not globally available. In these cases paleomagnetic data derived from the sediments might help to confirm or establish chronologies as will be illustrated in the following chapter.

Paleomagnetism and magnetostratigraphy

Magnetostratigraphy uses magnetic parameters to describe, correlate, and date sediment sequences (Lowrie 2007). Usually this term is associated with recorded polarity reversals of the geomagnetic field on long time scales (Opdyke & Channell 1996). However, in principle, any rock magnetic parameter could be used (Lowrie

2007). In this thesis the focus will be on magnetic susceptibility and paleomagnetic secular variations which are very important in terms of chronostratigraphy especially when dealing with young, i.e., (Late) Holocene sediments.

Magnetic susceptibility

Often the first paleomagnetic measurement is low field magnetic susceptibility which has evolved as a standard technique in core to core correlation on cores from a coherent depositional environment (Thompson 1986; Opdyke & Channell 1996; Ellwood 2007; Maher 2007; Merrill & McFadden 2007; Roberts 2007; Haberzettl *et al.* 2009, Appendix 9; Kastner *et al.* 2010, Appendix 18; Roberts & Turner 2013; Ahlborn *et al.* 2015, Appendix 1; Akita *et al.* 2015, Appendix 2) (Fig. 2). Magnetic susceptibility has the advantage to be measured simple, fast, and easy (Binford *et al.* 1983; Evans & Heller 2003; Ellwood 2007). It measures the magnetizability of a sample which is the

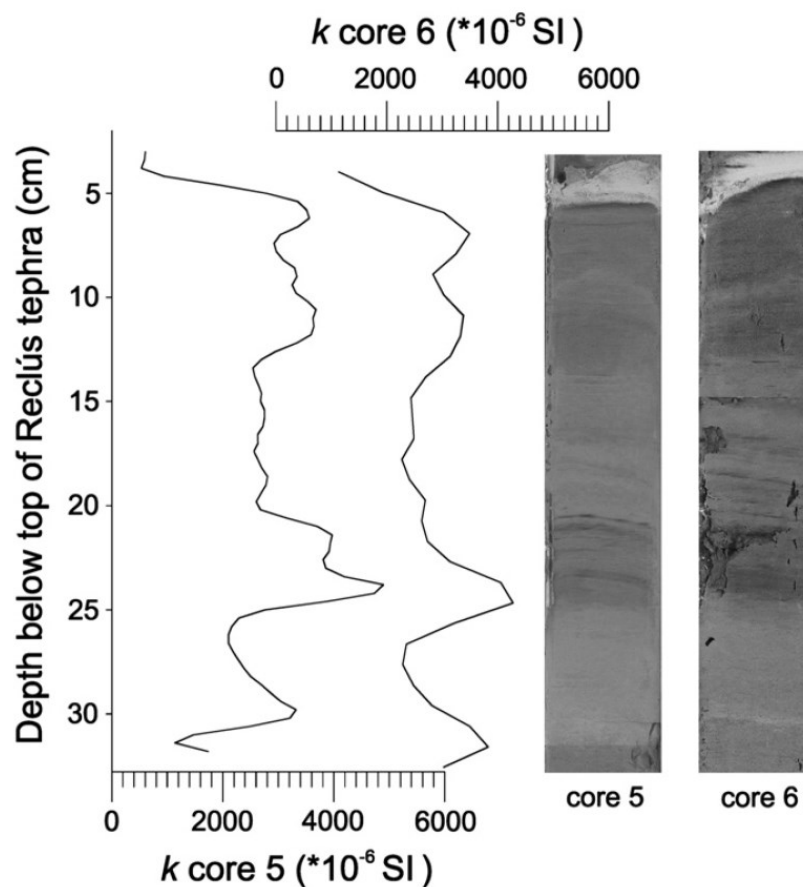


Fig. 2: Core to core correlation using magnetic susceptibility (k) on sediment cores from a coherent depositional environment (Haberzettl *et al.* 2009, Appendix 9).

magnetization of the samples in response to an applied magnetic field. Different mineralogical compositions, concentrations of certain minerals, and their magnetic grain size and morphology affect the magnetic susceptibility signal (Ellwood 2007; Hatfield & Stoner 2013). Therefore magnetic susceptibility can for example help to detect the allochthonous minerogenic input as it has often been the case in various paleolimnological studies (Thompson *et al.* 1975; Niemann *et al.* 2009, Appendix 25; Kastner *et al.* 2010, Appendix 18) (Fig. 3).

If the source of the sediment is very heterogeneous magnetic susceptibility can be used as a provenance indicator (Haberzettl *et al.* 2010, Appendix 10). For example in Hudson Bay and Strait the final outburst flood of Lake Agassiz-Ojibway deposited a so-called red bed in this area which compared to the surrounding geology yields low magnetic susceptibility due to a dominance of hematite (Haberzettl *et al.* 2010, Appendix 10). In the same study in combination with total inorganic carbon (TIC) it was possible to further distinguish between Paleozoic limestone sources underlying parts of Hudson Bay and Strait and Precambrian granitoids from the Canadian Shield (Haberzettl *et al.* 2010, Appendix 10).

A density related settling of comparatively heavy magnetic minerals within a magnetically weak matrix can also create a characteristic magnetic susceptibility signal (Hatfield & Stoner 2013). Magnetic susceptibility spikes can therefore help to identify turbidite layers and to distinguish them from background sedimentation (Hatfield & Stoner 2013; Ahlborn *et al.* 2015, Appendix 1; Akita *et al.* 2015, Appendix 2).

Based on comparisons with dust records from Antarctica low field magnetic susceptibility was also suggested as a dust indicator at Laguna Potrok Aike (Argentina)

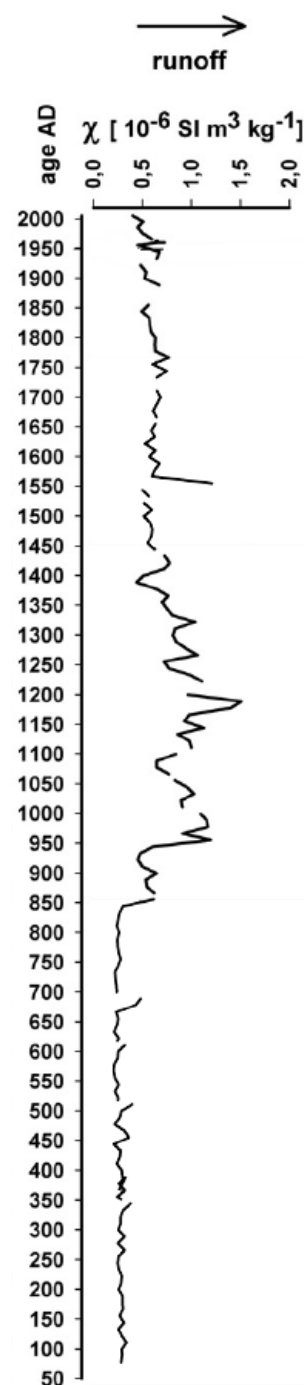


Fig. 3: Magnetic susceptibility reflecting minerogenic input (in this case by runoff) to a depositional system (Kastner *et al.* 2010, Appendix 18, modified).

which is located in the dust source of southern Patagonia (Haberzettl *et al.* 2009, Appendix 9). Within this archive the difference in magnetic susceptibility between glacial and Holocene times, in concert with the contemporaneous change in grain size as well as the dependency of magnetic susceptibility on grain size (Hatfield & Stoner 2013) indicates a causal relationship between these two parameters (Haberzettl *et al.* 2009, Appendix 9). This suggests that magnetic susceptibility might be used as chronostratigraphic tool which was similarly assumed for carbonate-free pelagic sediments from the Southern Ocean to constrain chronologies (Pugh *et al.* 2009; Weber *et al.* 2012). However, interpreting magnetic susceptibility records is seldom straightforward (Haberzettl *et al.* 2009, Appendix 9; Lisé-Pronovost *et al.* 2015, Appendix 21). It is rarely possible to determine the factors driving the magnetic susceptibility signal from the measured susceptibility signal alone. Therefore, a greater suite of magnetic measurements is necessary (Hatfield & Stoner 2013). More detailed magnetic studies on the sediments of Laguna Potrok Aike revealed that magnetic susceptibility reflects the estimated flux of magnetite to the lake and therefore low field magnetic susceptibility can only be interpreted as a dust indicator and for chronostratigraphic purposes at the millennial time scale (Lisé-Pronovost *et al.* 2015, Appendix 21). In contrast, the median destructive field of isothermal remanent magnetization (MDF_{IRM}) was established as a wind intensity indicator at the centennial time scale at Laguna Potrok Aike (Lisé-Pronovost *et al.* 2015, Appendix 21).

As has been shown in this paragraph magnetic susceptibility has many applications in modern paleolimnology if the process leading to a specific signal is well understood. Therefore, it is essential to interpret the individual magnetic susceptibility record within the context of its location and processes acting in its formation (Hatfield & Stoner 2013). In some cases magnetic susceptibility can even be used for stratigraphic purposes to establish chronologies. However, a much higher potential for stratigraphic purposes is in the application of magnetostratigraphy by using paleomagnetic secular variations (PSV) as described in the following.

Paleomagnetic secular variation (PSV) stratigraphy

As magnetic particles in lakes settle down and get deposited they align themselves with the ambient geomagnetic field (Tauxe 1993; Roberts & Turner 2013) and act like a compass needle (Merrill & McFadden 2007). Subsequently, when further sediment is deposited on top they are mechanically locked-in and therefore preserve the directional record (Fig. 4).

Magnetostratigraphy has long been used as a dating tool and it adds a significant new dimension to paleolimnological studies (Oldfield & Richardson 1990). Up to now the focus has mostly been on the difference between normally and reversed polarity of sedimentary archives the so called Geomagnetic Polarity Time Scale (GPTS). This concept was developed in the early 1960s (Cox *et al.* 1963; Opdyke & Channell 1996; Laj & Channell 2007; Singer 2007; Stoner & St-Onge 2007) when according to their polarity sediment sequences were divided in polarity chrons (Lowrie 2007). The midpoint of the last magnetic reversal, the Brunhes-Matuyama transition occurred at some time between 786.1 ± 1.5 ka (Sagnotti *et al.* 2014) and 773.1 ± 0.4 ka (Channell *et al.* 2010) or 773 ± 1 ka (Singer 2014). However, due to a scarcity of records with long time scales this rather simple method cannot be applied to many lacustrine archives.

On shorter time scales geomagnetic excursions might help. However, Roberts & Turner (2013) argue that excursions are the most abused geomagnetic phenomena and should if at all only be used with extreme caution unless they are accompanied by precise additional chronological constraints since such single events could also be caused by sediment deformation. Geomagnetic excursions occur rather frequently (Laj & Channell 2007) and are described as short episodes when the magnetic field of the

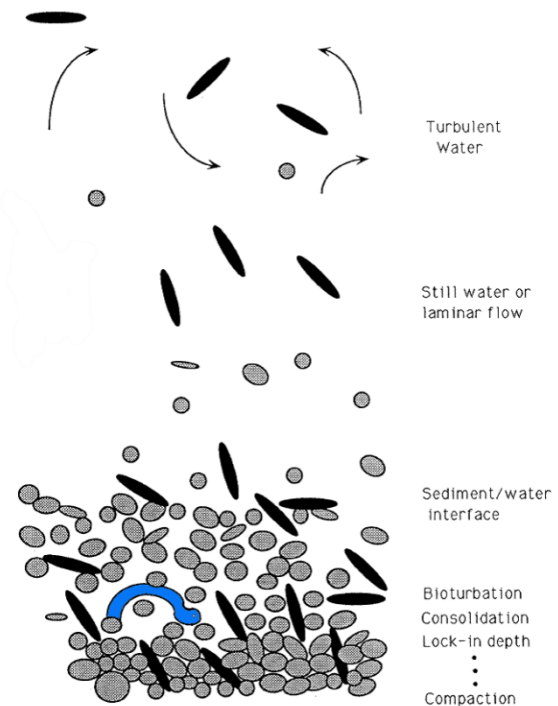


Fig. 4: Settling of magnetic particles and subsequent lock-in (Tauxe 1993, modified).

Earth deviates into an intermediate polarity (Roberts 2008) or simply as a significant departure from the geocentric axial dipole (King & Peck 2001) beyond the normal range of secular variations (Lund *et al.* 2006; Laj & Channell 2007; Lund 2007). The discovery of 27 well-documented geomagnetic field instabilities manifested in excursions that occurred during the Quaternary with 14 of them occurring during the Brunhes polarity chron (the most recent one we are living in) contributed to the compilation of a geomagnetic instability time scale (GITS) which also delineates the many excursions that took place during periods of stable polarity (Singer 2014). However, this must be viewed as a work in progress that will be subject to refinement in the near future (Singer 2014) as there is no general consensus about the number of excursion found during the Brunhes chron so far (Laj & Channell 2007; Lund 2007). The best known and investigated excursions are the Laschamp Event (40.7 ± 1 ka) (Singer *et al.* 2009) and the Mono Lake Event (32.4 ± 0.3 ka) (Singer 2007). Both have been demonstrated to occur globally (Lund 2007; Roberts 2008) and either of them (Mazaud *et al.* 2002) or both (Cassata *et al.* 2008; Lisé-Pronovost *et al.* 2013, Appendix 20) were also found on the southern hemisphere. However, ages for these swings differ significantly in many studies (Lisé-Pronovost *et al.* 2013, Appendix 20). Another geomagnetic excursion, the Hilina Pali excursion is less pronounced and not well established yet (Teanby *et al.* 2002). Although still much debated it probably occurred between 17 ka (Laj *et al.* 2002; Singer 2014) and 22 ka cal BP (Peck *et al.* 1996; Nowaczyk & Knies 2000; Nowaczyk *et al.* 2003) when distinct inclination lows were found in these studies. It was also found recently in Fram Strait in various archives (Haberzettl unpublished data) and potentially at Laguna Potrok Aike (Argentina) (Lisé-Pronovost *et al.* 2013, Appendix 20).

Nevertheless, covering 'only' 20 ka is also a challenge for many lacustrine sequences. On shorter time scales smaller geomagnetic directional shifts are called paleomagnetic secular variations (PSVs) (Thompson 1986; Stoner & St-Onge 2007). PSVs which can be used as chronostratigraphic tool especially during the Holocene appear to be better suited for dating purposes than geomagnetic excursion (Roberts & Turner 2013). The first study on PSVs was carried out by Mackereth (1971) on lacustrine sediments from Lake Windermere, UK, where changes in declination were investigated (Creer & Tucholka 1983; Oldfield & Richardson 1990). "This work paved the way for the development of the field of secular variation magnetic

stratigraphy” (Opdyke & Channell 1996) and paleomagnetic “work on lake sediments mushroomed” (Creer & Tucholka 1983). Due to the convenience of not having to open or extrude the cores often only declination was measured these days (Dearing 1986; Oldfield & Richardson 1990; Leemann & Niessen 1994; Opdyke & Channell 1996). Inclination measurements required the cores to be opened and subsampled (Oldfield & Richardson 1990). More recently inclination records turned out to be often more suitable in lacustrine environments, especially in lower latitudes (Creer & Tucholka 1983; Thompson 1986; Oldfield & Richardson 1990; Anker *et al.* 2001; Haberzettl *et al.* 2015, Appendix 13). Although the spatial occurrence of lakes suitable for PSV studies is rather erratic most studies establishing PSV records originate from this environment since sedimentation rates in marine archives are often too low for high-resolution records (Opdyke & Channell 1996). However, PSV records from lakes are still patchy with distinct gaps in Tibet (Haberzettl *et al.* 2015, Appendix 13) and the other regions investigated in this thesis (Korte & Constable 2011; Korte *et al.* 2011) (Fig. 5).

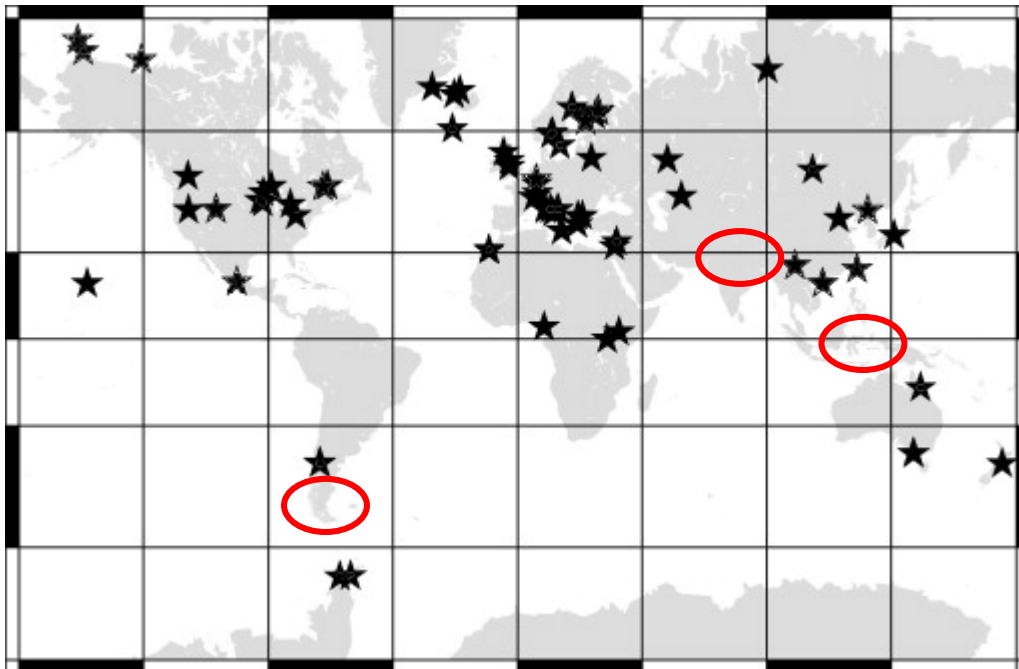


Fig. 5: Distribution of sediment records contained in the CALS3k.3 global geomagnetic field model (stars) covering the past 3,000 years. Red ellipses indicate new records obtained within this thesis (Korte & Constable 2011, modified).

Due to the absence of measured PSV records magnetostratigraphic comparisons in this thesis were initially drawn with global geomagnetic field models like the CALS3k.x (Korte *et al.* 2009), the CALS7k.2 (Korte *et al.* 2005), or the pfm9k (Nilsson *et al.* 2014) model (Kasper *et al.* 2012, Appendix 15; Haberzettl *et al.* 2013, Appendix 11; Ahlborn *et al.* 2015, Appendix 1). This already helped to improve reservoir effect affected radiocarbon based chronologies distinctively. Unfortunately, such models are limited by the reliability of incorporated data, age uncertainties, and the regional bias of data availability (Yu *et al.* 2010). This means that due to a lack of data comparisons to such models are sometimes unreliable. This is especially the case for Patagonia (Ohlendorf *et al.* 2014, Appendix 27) and to a certain extend for Tibet before 2 ka cal BP (Haberzettl *et al.* 2015, Appendix 13). Hence, after an initial comparison with the models it was always tried to build a data base (≥ 2 records) with various archives for comparison which was successfully accomplished for Sulawesi (Biagioni *et al.* 2015, Appendix 3) and Tibet (Haberzettl *et al.* 2015, Appendix 13) within this thesis.

Finally, it has to be mentioned that each site has to be tested if PSVs can be used as chronostratigraphic tool since not all sediment sequences are suited for paleomagnetic dating (Oldfield & Richardson 1990). Only 20 % of all lake studies generated inclination and declination records are suited for correlation (Opdyke & Channell 1996). In general it is difficult to predict which sites are suited and which are not, though some controlling factors have become apparent (Dearing 1986; Oldfield & Richardson 1990):

- a) In coarse grained sediments such as sand the paleomagnetic remanence is not sufficiently well locked to retain a signal from the ambient magnetic field of the Earth at the time of deposition. Therefore, sediments dominated by coarse grains usually do not faithfully record magnetic field information from the time of deposition (Roberts 2007; Roberts & Turner 2013).
- b) A high content of diamagnetic components such as carbonates, water, or organic matter and hence a low minerogenic proportion of the sediment often results in a weak unstable natural remanence.

However, once a regional master curve of PSVs is established this can be used as a chronostratigraphic tool (Lund *et al.* 2006) to date surrounding paleoenvironmental records (Oldfield & Richardson 1990) with a precision of decadal to millennial-scale resolution during the Holocene (Roberts & Turner 2013). Due to non-dipolar

components of the magnetic field of the earth this PSV stratigraphy is limited to the continental scale (Roberts & Turner 2013), i.e., a certain area around the type site typically ranging between 1,000 - 2,000 km (Thompson 1986; Oldfield & Richardson 1990; Lund *et al.* 2006) and 3,000 - 5,000 km (King & Peck 2001; Lund 2007). Around the Tibetan Plateau PSV similarities over an area of >3,000 km have been observed in this thesis (Haberzettl *et al.* 2015, Appendix 13).

Multi-dating-approach

The most powerful tool to obtain accurate chronologies from lacustrine archives is a multi-dating-approach (King & Peck 2001). This could consist of radiocarbon dating on various materials (e.g., organic bulk, inorganic bulk, terrestrial organic matter, etc.) (Haberzettl *et al.* 2005), component specific radiocarbon dating (e.g., lignin phenols) (Hou *et al.* 2010), optical dating (Long *et al.* 2015, Appendix 23), $^{230}\text{Th}/^{234}\text{U}$ -dating (Wagner 1998), tephrochronology (Haberzettl *et al.* 2007; Haberzettl *et al.* 2009, Appendix 9), radioisotopes ($^{137}\text{Cs}/^{210}\text{Pb}$) in the most recent part (Kasper *et al.* 2012, Appendix 15; Haberzettl *et al.* 2015, Appendix 13), etc. Subsequently, chronologies should be evaluated using magnetostratigraphy (Kasper *et al.* 2012, Appendix 15; Haberzettl *et al.* 2015, Appendix 13). Such approaches need to bring together various expertise and disciplines. However, such an approach often suffers from insufficient time and/or manpower to carry out all these investigations. In some cases also the material turns out to be unsuitable for one or the other method. Within this thesis such an approach was aimed for Lake Tangra Yumco on the Tibetan Plateau. Here radiocarbon dating of lignin phenols and $^{230}\text{Th}/^{234}\text{U}$ -dating turned out not to be feasible. Therefore, the focus was put on radiocarbon dating of a piece of wood and reservoir corrected bulk ages (Haberzettl *et al.* 2015, Appendix 13) (Fig. 1). The chronology was tested with optical dating revealing ages in the range of the reservoir corrected ages (Long *et al.* 2015, Appendix 23) and magnetostratigraphy (Haberzettl *et al.* 2015, Appendix 13) confirming this approach.

Conclusions and Outlook

The analysis of lacustrine sediments to extract paleoenvironmental information is a very promising field of research. Their study needs a multidisciplinary approach which involves different proxies, proxy calibration- and monitoring studies, allowing paleoenvironments and paleoclimate, as well as recent climate change, to be investigated with increasing accuracy (Verrecchia 2008). However, it is still a long way to go to fully understand lacustrine systems and their paleoclimatic significance. Any new piece of information will take us closer to the ultimate goal of understanding lacustrine environments through space and time (Cabrera *et al.* 2009).

Future work beyond this thesis will contribute to a better understanding of system processes, system interactions, and system feedbacks. For this purpose parallel investigations on different but neighboring systems should be carried out. For example a small lake with a limited catchment located close to a larger system could be investigated. Both systems continuously record environmental changes. While the larger system records processes occurring over a large area in the small system large-scale changes might be overprinted by local information. Comparing the two systems (including catchment and monitoring results) and their respective records will provide a deeper insight in processes acting on diverse spatio-temporal scales. First steps concerning this approach are on the way in southern central Tibet where processes affecting the large system of Lake Tangra Yumco (Akita *et al.* 2015, Appendix 2) and two smaller systems (Miehe *et al.* 2014, Appendix 24; Ahlborn *et al.* 2015, Appendix 1) located in the catchment area of this lake have been investigated. Future detailed comparisons will allow for a differentiation of processes acting on different spatial and temporal scales and hence contribute to a better understanding of the individual system.

Most other studies presented in this thesis are also planned to continue in future. Further manuscripts about Tibet, South Africa, and Hudson Bay are in preparation. Additionally, processing of already measured paleomagnetic data from Eilandvlei (South Africa), Xuru and Peiku Co (Tibet), Fram Strait, Maxwell Bay (Antarctica), and some sites in Patagonia (Argentina) is in progress.

In terms of limnogeological investigations future work will focus on the extension of the existing paleoenvironmental database which was gathered within the RAIN (Regional Archives for Integrated iNvestigations) project (Haberzettl *et al.* 2014, Appendix 12). Based on investigations of terrestrial and marine paleoenvironmental archives in different rainfall zones in South Africa, RAIN assesses the compatibility of the two types of archives in terms of past climate and ecosystem changes and contributes to an improved knowledge of land-ocean interactions by following transport pathways from source to sink (Haberzettl *et al.* 2014, Appendix 12). Up to now from the year-round rainfall zone sediment cores have been recovered in 2013 from offshore and onshore the Wilderness Coastal Section of the Garden Route National Park. Cores have already been opened and analyzed using a large suite of parameters for paleoenvironmental reconstruction. In terms of paleomagnetic measurements it turned out that marine sediments are unsuited for PSV reconstructions in this area. This might be the consequence of dilution of the sediment by diamagnetic marine carbonates. Lacustrine facies showed a sufficiently high magnetization on sediments from Lakes Eilandvlei and Swartvlei (Haberzettl unpublished data). A similar picture was observed on the West Coast of South Africa, where the top sediments of Lake Verlorenvlei have a sufficiently high magnetization but offshore sediments do not. Paleolimnological investigations at Verlorenvlei just started in 2014 but are very promising.

In Tibet the successful work as also seen in this thesis during the past years within the DFG (German Research Foundation) priority program 1372 TiP (Tibetan Plateau: Formation-Climate-Ecosystems) and the BMBF (German Federal Ministry of Education and Research) funded CAME (Central Asia – Monsoon dynamics and Geoecosystems) program encouraged some colleagues including myself to promote a deep drilling effort at Lake Nam Co within the framework of the International Continental Scientific Drilling Program (ICDP). Preliminary seismic investigations revealed a sediment thickness of at least 800 m since no bottom reflector was found down to this depth (Spiess *et al.* 2014). A conservative age estimation results in an age of 460 to 1,900 ka for this seismically imaged sequence (Spiess *et al.* 2014). This will result in an enormous amount of paleoenvironmental information from paleoclimatic studies, molecular clock investigations, and tectonic research.

According to the stratigraphic interpretation of the preliminary seismic data, continuous sedimentation at Nam Co occurred during several glacial-interglacial

cycles. Considering the short time coverage of other continuous lacustrine records on the Tibetan Plateau (<32 ka) this makes Nam Co the perfect site to study large-scale atmospheric circulation variations (Monsoon and Westerlies) on much longer time scales. This is of paramount significance since from the whole area information on past interglacials, especially the ones which are commonly regarded as analogue to the Holocene like Marine Isotope Stage (MIS) 11 (McManus *et al.* 2013), are lacking. Nam Co might provide a unique opportunity to study the internal variability of MIS 11 in Southeast Asia. Analyses of such analogues could be very valuable for the understanding of the interactions of climate systems such as Monsoon and Westerlies enabling better future climate scenarios. Up to now only few terrestrial records covering this interval have been recovered. However, these are not close to Nam Co (Rousseau 2013).

So far it also remains unclear how the atmospheric circulation systems changed on the Tibetan Plateau during older glacial-interglacial cycles (or even interstadials). From the last glacial-interglacial transition it is known that changes from a dry and cold to a moist and warm environment occurred very fast with a strong moisture pulse in the early Holocene, i.e., within <1000 years (Kasper *et al.* 2015, Appendix 17). However, transitions from interglacial to glacial conditions have not been observed in this area yet.

Based on dating of ancient lake level terraces around Nam Co, Zhu *et al.* (2004) reconstructed an “Ancient Large Lake” on the TP for the period between 115 and 40 ka BP incorporating Nam Co. However, no continuous hydrological information is available for this interval, inhibiting a detailed investigation of hydrological variations in this area. The recovery of continuous records would allow to study feedback mechanisms of a “Pan-Lake” environment to the surrounding area (e.g., vegetation) or to the climate system itself. Such a large water body would likely cause intensive water recycling on the Tibetan Plateau in addition to or in contrast to monsoon influence.

From the paleomagnetic perspective the recovery of a long drill core from Nam Co means that many excursion of the Brunhes chron potentially the Brunhes-Matuyama transition will be contained in this record in high-resolution since sedimentation rates at Nam Co can reach up to 2.4 mm a^{-1} (Kasper *et al.* 2015, Appendix 17).

Besides the deep drilling of Nam Co another major future aim will be the construction of a PSV stack for the Tibetan Plateau. Currently eight short lasting

records between 400 and 4,000 years are available although not yet completely processed and more sediment records will be measured in the near future. Once, reliable chronologies are available for the records this task will be addressed. Similar PSV stacks have previously been published for East Asia (Zheng *et al.* 2014), eastern Canada (Barletta *et al.* 2010), northeastern United States (King & Peck 2001), Fennoscandia (Snowball *et al.* 2007; Lougheed *et al.* 2014), central-northern Great Britain (Turner & Thompson 1981), and the West Eifel (Germany) (Stockhausen 1998). Such a stack for Tibet bears the great potential to be used as a reference curve for dating purposes for a very large region.

Outline and structure of the thesis

The aim of this thesis is to provide new paleolimnological and limnogeological information and develop conceptual approaches from areas of the world where this kind of information is very scarce to (almost) inexistent such as the steppe parts of southern Patagonia (Argentina), the eastern Ecuadorian Andes, the Island of Sulawesi (Indonesia), the epicontinental sea of the Hudson Bay, the Tibetan Plateau, or the different rainfall zones of South Africa. A special emphasis will be on the construction of reliable chronologies using multi-dating approaches. In this context one focus will be on the evaluation of chronologies using PSVs wherever this was possible depending on sediment properties.

For this thesis only internationally published peer-reviewed articles are considered. Although, some contributions are from Laguna Potrok Aike which was the investigated site of my PhD thesis (Haberzettl 2006) all contributions to this habilitation thesis postdate the successful completion of the PhD thesis and were hence compiled independently. Even though the papers are in alphabetical order they can be structured as follows:

1. New conceptual approaches
2. Paleoenvironmental reconstructions using simple magnetostratigraphically not confirmed chronologies since no paleomagnetic secular variation data could be obtained from the sediment and other paleolimnological and limnogeological investigations such as studies on sediment distributions (including one marine study from the epicontinental sea of the Hudson Bay)
3. Paleomagnetic investigations and/or magnetostratigraphic evaluations of chronologies
4. Paleoenvironmental information from magnetostratigraphically corroborated chronologies
5. Other dating approaches

Table 1: List of manuscripts used for this thesis. No. corresponds to the appendix number. Category refers to the categorization given on the previous page.

No.	Manuscript	Category	Contribution to
1	Ahlborn M., Haberzettl T. , Wang J., Alivernini M., Schlütz F., Schwarz A., Su Y., Frenzel P., Daut G., Zhu L. & Mäusbacher R. (2015): Sediment dynamics and hydrologic events affecting small lacustrine systems on the southern-central Tibetan Plateau – the example of TT Lake. <i>The Holocene</i> 25(3), 508-522.	1, 3, 4	concept of research approach / data acquisition / data analysis and interpretation / writing manuscript
2	Akita L.G., Frenzel P., Haberzettl T. , Kasper T., Wang J. & Reicherter K. (2015): Ostracoda (Crustacea) as indicators of subaqueous mass movements: An example from the large brackish lake Tangra Yumco on the southern Tibetan Plateau, China. <i>Palaeogeography, Palaeoclimatology, Palaeoecology</i> 419, 60-74.	1	data acquisition for physical and geochemical sediment properties / comparison to physical and chemical sediment properties / writing manuscript
3	Biagioni S., Haberzettl T. , Wang L., St-Onge G. & Behling H. (2015): Unravelling the past 1,000 years of history of human-climate-landscape interactions at the Lindu plain (Sulawesi, Indonesia). <i>Vegetation History and Archaeobotany</i> , doi:10.1007/s00334-015-0523-1	3, 4	concept of research approach / paleomagnetic data acquisition / data analysis and interpretation / writing manuscript
4	Biagioni S., Wündsche M., Haberzettl T. & Behling H. (2015): Assessing resilience/sensitivity of tropical mountain rainforests towards climate variability of the last 1500 years: The long-term perspective at Lake Kalimpa (Sulawesi, Indonesia). <i>Review of Palaeobotany and Palynology</i> 213, 42-53.	4	concept of research approach / stratigraphy / chronology / discussion of data in context of chemical sediment properties
5	Brunschön C., Haberzettl T. & Behling H. (2010): High-resolution studies on vegetation succession, hydrological variations, anthropogenic impact and genesis of a subrecent lake in southern Ecuador. <i>Vegetation History and Archaeobotany</i> 19(3), 191-206.	2	concept of research approach / data acquisition for geochemical sediment properties / data analysis and interpretation / writing manuscript
6	Dietze E., Maussion F., Ahlborn M., Diekmann B., Hartmann K., Henkel K., Kasper T., Locket G., Opitz S. & Haberzettl T. (2014): Sediment transport processes across the Tibetan Plateau inferred from robust grain-size end members in lake sediments. <i>Climate of the Past</i> 10(1), 91-106.	1	data acquisition and interpretation / writing manuscript

7	Doberschütz S., Frenzel P., Haberzettl T. , Kasper T., Wang J., Zhu L., Daut G., Schwalb A. & Mäusbacher R. (2014): Monsoonal forcing of Holocene paleoenvironmental change on the central Tibetan Plateau inferred using a sediment record from Lake Nam Co (Xizang, China). <i>Journal of Paleolimnology</i> 51(2), 253-266.	2, 4	concept of research approach / geochemical data analysis and interpretation
8	Fey M., Korr C., Maidana N.I., Carrevedo M.L., Corbella H., Dietrich S., Haberzettl T. , Kuhn G., Lücke A., Mayr C., Ohlendorf C., Paez M.M., Quintana F.A., Schäbitz F. & Zolitschka B. (2009): Palaeoenvironmental changes during the last 1600 years inferred from the sediment record of a cirque lake in southern Patagonia (Laguna Las Vizcachas, Argentina). <i>Palaeogeography, Palaeoclimatology, Palaeoecology</i> 281(3-4), 363-375.	2	concept of research approach / data analysis and interpretation
9	Haberzettl T. , Anselmetti F.S., Bowen S.W., Fey M., Mayr C., Zolitschka B., Ariztegui D., Mauz B., Ohlendorf C., Kastner S., Lücke A., Schäbitz F. & Wille M. (2009): Late Pleistocene dust deposition in the Patagonian steppe - extending and refining the paleoenvironmental and tephrochronological record from Laguna Potrok Aike back to 55 ka. <i>Quaternary Science Reviews</i> 28(25-26), 2927-2939.	1-5	concept of research approach / data assessment / data analysis and interpretation / writing manuscript
10	Haberzettl T. , St-Onge G. & Lajeunesse P. (2010): Multi-proxy records of environmental changes in Hudson Bay and Strait since the final outburst flood of Lake Agassiz-Ojibway. <i>Marine Geology</i> 271(1-2), 93-105.	2, 3	concept of research approach / data assessment / data analysis and interpretation / writing manuscript
11	Haberzettl T. , St-Onge G., Behling H. & Kirleis W. (2013): Holocene radiocarbon-based chronologies by matching palaeomagnetic secular variations to geomagnetic field models: an example from Lake Kalimpa (Sulawesi, Indonesia). In: Jovane L., Herrero-Bervera E., Hinnov L.A. & Housen B.A. (Eds.), <i>Magnetic Methods and the Timing of Geological Processes</i> . London: Geological Society London Special Publications. pp. 245-259.	3	concept of research approach / data acquisition / data analysis and interpretation / writing manuscript

12	Haberzettl T. , Baade J., Compton J., Daut G., Dupont L., Finch J., Frenzel P., Green A., Hahn A., Hebbeln D., Helmschrot J., Humphries M., Kasper T., Kirsten K., Mäusbacher R., Meadows M., Meschner S., Quick L., Schefuß E., Wündsche M. & Zabel M. (2014): Paleoenvironmental investigations using a combination of terrestrial and marine sediments from South Africa - The RAIN (Regional Archives for Integrated iNvestigations) approach. Zentralblatt für Geologie und Paläontologie, Teil I(1), 55-73.	1	concept of research approach / writing manuscript
13	Haberzettl T. , Henkel K., Kasper T., Ahlborn M., Su Y., Wang J., Appel E., St-Onge G., Stoner J., Daut G., Zhu L. & Mäusbacher R. (2015): Independently dated paleomagnetic secular variation records from the Tibetan Plateau. Earth and Planetary Science Letters 416, 98-108.	3	concept of research approach / data acquisition / data analysis and interpretation / writing manuscript
14	Jouve G., Francus P., Lamoureux S., Provencher-Nolet L., Hahn A., Haberzettl T. , Fortin D. & Nuttin L. (2013): Microsedimentological characterization using image analysis and μ -XRF as indicators of sedimentary processes and climate changes during Lateglacial at Laguna Potrok Aike, Santa Cruz, Argentina. Quaternary Science Reviews 71, 191-204.	2	data analysis and interpretation
15	Kasper T., Haberzettl T. , Doberschütz S., Daut G., Wang J., Zhu L., Nowaczyk N. & Mäusbacher R. (2012): Indian Ocean Summer Monsoon (IOSM)-dynamics within the past 4 ka recorded in the sediments of Lake Nam Co, central Tibetan Plateau (China). Quaternary Science Reviews 39, 73-85.	3, 4	concept of research approach / data acquisition / data analysis and interpretation / writing manuscript
16	Kasper T., Frenzel P., Haberzettl T. , Schwarz A., Daut G., Meschner S., Wang J., Zhu L. & Mäusbacher R. (2013): Interplay between redox conditions and hydrological changes in sediments from Lake Nam Co (Tibetan Plateau) during the past 4000 cal BP inferred from geochemical and micropaleontological analyses. Palaeogeography, Palaeoclimatology, Palaeoecology 392, 261-271.	4	concept of research approach / geochemical data acquisition / data analysis and interpretation

17	Kasper T., Haberzettl T. , Wang J., Daut G., Doberschütz S., Zhu L. & Mäusbacher R. (2015): Hydrological variations on the Central Tibetan Plateau since the Last Glacial Maximum and their teleconnection to inter-regional and hemispheric climate variations. <i>Journal of Quaternary Science</i> 30(1), 70-78.	2, 4	concept of research approach / data acquisition / data analysis and interpretation
18	Kastner S., Enters D., Ohlendorf C., Haberzettl T. , Kuhn G., Lücke A., Mayr C., Reyss J.-L., Wastegård S. & Zolitschka B. (2010a): Reconstructing 2000 years of hydrological variation derived from laminated proglacial sediments of Lago del Desierto at the eastern margin of the South Patagonian Ice Field, Argentina. <i>Global and Planetary Change</i> 72(3), 201-214.	2	concept of research approach / geophysical data acquisition / data analysis and interpretation
19	Kastner S., Ohlendorf C., Haberzettl T. , Lücke A., Mayr C., Maidana N., Schäbitz F. & Zolitschka B. (2010b): Southern hemispheric westerlies control the spatial distribution of modern sediments in Laguna Potrok Aike, Argentina. <i>Journal of Paleolimnology</i> 44(4), 887-902.	1	concept of research approach / data analysis and interpretation
20	Lisé-Pronovost A., St-Onge G., Gogorza C., Haberzettl T. , Preda M., Kliem P., Francus P. & Zolitschka B. (2013): High-resolution paleomagnetic secular variations and relative paleointensity since the Late Pleistocene in southern South America. <i>Quaternary Science Reviews</i> 71, 91-108.	3	concept of research approach / data interpretation
21	Lisé-Pronovost A., St-Onge G., Gogorza C., Haberzettl T. , Jouve G., Francus P., Ohlendorf C., Gebhardt C. & Zolitschka B. (2015): Rock-magnetic proxies of wind intensity and dust since 51,200 cal BP from lacustrine sediments of Laguna Potrok Aike, southeastern Patagonia. <i>Earth and Planetary Science Letters</i> 411, 72-86.	3	concept of research approach / data interpretation
22	Long H., Lai Z., Frenzel P., Fuchs M. & Haberzettl T. (2012): Holocene moist period recorded by the chronostratigraphy of a lake sedimentary sequence from Lake Tangra Yumco on the south Tibetan Plateau. <i>Quaternary Geochronology</i> 10, 136-142.	5	concept of research approach / data interpretation

23	Long H., Haberzettl T. , Tsukamoto S., Shen J., Kasper T., Daut G., Zhu L., Mäusbacher R. & Frechen M. (2015): Luminescence dating of lacustrine sediments from Tangra Yumco (southern Tibetan Plateau) using post-IR IRSL signals from polymineral grains. <i>Boreas</i> 44(1), 139-152.	5	concept of research approach / data assessment / data interpretation
24	Miehe S., Miehe G., van Leeuwen J.N., Wrozyna C., van der Knaap W., Duo L. & Haberzettl T. (2014): Persistence of Artemisia steppe in the Tangra Yumco Basin, west-central Tibet, China: despite or in consequence of Holocene lake-level changes? <i>Journal of Paleolimnology</i> 51(2), 267-285.	2	concept of research approach / chronology / sedimentology / data interpretation / writing manuscript
25	Niemann H., Haberzettl T. & Behling H. (2009): Holocene climate variability and vegetation dynamics inferred from the (11700 cal. yr BP) Laguna Rabadilla de Vaca sediment record, southeastern Ecuadorian Andes. <i>The Holocene</i> 19(2), 307-316.	2	geophysical and geochemical data interpretation
26	Ohlendorf C., Fey M., Gebhardt C., Haberzettl T. , Lücke A., Mayr C., Schäbitz F., Wille M. & Zolitschka B. (2013): Mechanisms of lake-level change at Laguna Potrok Aike (Argentina) – insights from hydrological balance calculations. <i>Quaternary Science Reviews</i> 71, 27-45.	2	data acquisition and interpretation
27	Ohlendorf C., Fey M., Massaferro J., Haberzettl T. , Laprida C., Lücke A., Maidana N., Mayr C., Oehlerich M., Ramón Mercau J., Wille M., Corbella H., St-Onge G., Schäbitz F. & Zolitschka B. (2014): Late Holocene hydrology inferred from lacustrine sediments of Laguna Cháltel (southeastern Argentina). <i>Palaeogeography, Palaeoclimatology, Palaeoecology</i> 411, 229-248.	3, 4	concept of research approach / paleomagnetic data acquisition / data analysis and interpretation / writing manuscript
28	Recasens C., Ariztegui D., Gebhardt C., Gogorza C., Haberzettl T. , Hahn A., Kliem P., Lisé-Pronovost A., Lücke A., Maidana N., Mayr C., Ohlendorf C., Schäbitz F., St-Onge G., Wille M., Zolitschka B. & the PASADO Science Team (2012): New insights into paleoenvironmental changes in Laguna Potrok Aike, southern Patagonia, since the Late Pleistocene: The PASADO multiproxy record. <i>The Holocene</i> 22(11), 1323-1335.	2, 3	magnetic characterization of sediments

29	Reinwarth B., Franz S., Baade J., Haberzettl T. , Kasper T., Daut G., Helmschrot J., Kirsten K.L., Quick L.J., Meadows M.E. & Mäusbacher R. (2013): A 700-year record on the effects of climate and human impact on the southern Cape coast inferred from lake sediments of Eilandvlei, Wilderness Embayment, South Africa. <i>Geografiska Annaler: Series A, Physical Geography</i> 95(4), 345-360.	2	concept of research approach / data analysis and interpretation
30	Schäbitz F., Wille M., Francois J.-P., Haberzettl T. , Quintana F., Mayr C., Lücke A., Ohlendorf C., Mancini V., Paez M.M., Prieto A.R. & Zolitschka B. (2013): Reconstruction of palaeoprecipitation based on pollen transfer functions – the record of the last 16 ka from Laguna Potrok Aike, southern Patagonia. <i>Quaternary Science Reviews</i> 71, 175-190.	2	discussion of results in comparison to geochemical parameters
31	Su Y., Gao X., Liu Q., Hu P., Duan Z., Jiang Z., Wang J., Zhu L., Doberschütz S., Mäusbacher R., Daut G. & Haberzettl T. (2013a): Mechanism of variations in environmental magnetic proxies of lake sediments from Nam Co, Tibet during the Holocene. <i>Chinese Science Bulletin</i> 58(13), 1568-1578.	3	concept of research approach / data interpretation
32	Su Y., Gao X., Liu Q., Wang J., Haberzettl T. , Zhu L., Li J., Duan Z. & Tian L. (2013b): Mineral magnetic study of lacustrine sediments from Lake Pumoyum Co, southern Tibet, over the last 19 ka and paleoenvironmental significance. <i>Tectonophysics</i> 588, 209-221.	3	data interpretation
33	Wündsche M., Biagioni S., Behling H., Reinwarth B., Franz S., Bierbaß P., Daut G., Mäusbacher R. & Haberzettl T. (2014): ENSO and monsoon variability during the past 1.5 kyr as reflected in sediments from Lake Kalimpa, Central Sulawesi (Indonesia). <i>The Holocene</i> 24(12), 1743-1756.	4	concept of research approach / data acquisition / data analysis and interpretation

References

- Ahlborn M., Haberzettl T., Wang J., Alivernini M., Schlütz F., Schwarz A., Su Y., Frenzel P., Daut G., Zhu L. & Mäusbacher R. (2015): Sediment dynamics and hydrologic events affecting small lacustrine systems on the southern-central Tibetan Plateau – the example of TT Lake. *The Holocene* 25(3), 508-522.
- Akita L.G., Frenzel P., Haberzettl T., Kasper T., Wang J. & Reicherter K. (2015): Ostracoda (Crustacea) as indicators of subaqueous mass movements: An example from the large brackish lake Tangra Yumco on the southern Tibetan Plateau, China. *Palaeogeography, Palaeoclimatology, Palaeoecology* 419, 60-74.
- Anker S.A., Colhoun E.A., Barton C.E., Peterson M. & Barbetti M. (2001): Holocene Vegetation and Paleoclimatic and Paleomagnetic History from Lake Johnston, Tasmania. *Quaternary Research* 56(2), 264-274.
- Anselmetti F.S., Ariztegui D., De Batist M., Gebhardt C., Haberzettl T., Niessen F., Ohlendorf C. & Zolitschka B. (2009): Environmental history of southern Patagonia unravelled by the seismic stratigraphy of Laguna Potrok Aike. *Sedimentology* 56(4), 873-892.
- Barletta F., St-Onge G., Stoner J.S., Lajeunesse P. & Locat J. (2010): A high-resolution Holocene paleomagnetic secular variation and relative paleointensity stack from eastern Canada. *Earth and Planetary Science Letters* 298(1-2), 162-174.
- Biagioni S., Haberzettl T., Wang L.-C., St-Onge G. & Behling H. (2015): Unravelling the past 1,000 years of history of human–climate–landscape interactions at the Lindu plain, Sulawesi, Indonesia. *Vegetation History and Archaeobotany*, 10.1007/s00334-00015-00523-00331.
- Biagioni S., Wündsche M., Haberzettl T. & Behling H. (2015): Assessing resilience/sensitivity of tropical mountain rainforests towards climate variability of the last 1500 years: The long-term perspective at Lake Kalimpa (Sulawesi, Indonesia). *Review of Palaeobotany and Palynology* 213, 42-53.
- Binford M.W., Deevey E.S. & Crisman T.L. (1983): Paleolimnology: An Historical Perspective on Lacustrine Ecosystems. *Annual Review of Ecology and Systematics* 14(1), 255-286.
- Birks H.H. & Birks H.J.B. (2006): Multi-proxy studies in palaeolimnology. *Vegetation History and Archaeobotany* 15(4), 235-251.
- Birks H.J.B. (2012): Conclusions and Future Challenges. In: Birks H.J.B., Lotter A.F., Juggins S. & Smol J.P. (Eds.), *Tracking Environmental Change Using Lake Sediments - Data Handling and Numerical Techniques - Developments in Paleoenvironmental Research Volume 5*. Dordrecht: Springer. pp. 643-673.
- Bradley R.S. & Eddy J.A. (1991): Records of Past Global Changes. In: Bradley R.S. (Ed.), *Global Changes of the Past*. Boulder: University Corporation for Atmospheric Research. pp. 5-9.
- Bradley R.S. (1999): *Paleoclimatology. Reconstructing climates of the quaternary*. San Diego, Calif.: Harcourt/Academic Press.
- Cabrera L., Gierlowski Kordesch E.H., Alonso-Zarza A.M. & Arenas Abad C. (2009): Limnogeology: Ancient and modern tales of an evolving Earth. *Sedimentary Geology* 222(1-2), 1-4.
- Cassata W.S., Singer B.S. & Cassidy J. (2008): Laschamp and Mono Lake geomagnetic excursions recorded in New Zealand. *Earth and Planetary Science Letters* 268(1-2), 76-88.
- Channell J.E.T., Hodell D.A., Singer B.S. & Xuan C. (2010): Reconciling astrochronological and ⁴⁰Ar/³⁹Ar ages for the Matuyama-Brunhes boundary and late Matuyama Chron. *Geochemistry, Geophysics, Geosystems* 11(12), Q0AA12.
- Collinson J.D. (1978): Lakes. In: Reading H.G. (Ed.), *Sedimentary environments and facies*. London: Blackwell Scientific Publications. pp. 61-79.
- Cox A., Doell R.R. & Dalrymple G.B. (1963): Geomagnetic Polarity Epochs and Pleistocene Geochronometry. *Nature* 198, 1049-1051.
- Creer K.M. & Tucholka P. (1983): On the current state of lake sediment palaeomagnetic research. *Geophysical Journal of the Royal Astronomical Society* 74(1), 223-238.
- Dearing J.A. (1986): Core correlation and total sediment influx. In: Berglund B.E. (Ed.), *Handbook of holocene palaeoecology and palaeohydrology*. Chichester: Wiley. pp. 247-270.
- Doberschütz S., Frenzel P., Haberzettl T., Kasper T., Wang J., Zhu L., Daut G., Schwalb A. & Mäusbacher R. (2014): Monsoonal forcing of Holocene paleoenvironmental change on the central Tibetan Plateau inferred using a sediment record from Lake Nam Co (Xizang, China). *Journal of Paleolimnology* 51(2), 253-266.

- Ellwood B.B. (2007): Magnetic susceptibility (MS), low-field. In: Gubbins D. & Herrero-Bervera E. (Eds.), *Encyclopedia of Geomagnetism and Paleomagnetism*: Springer Netherlands. pp. 566-572.
- Evans M. & Heller F. (2003): *Environmental Magnetism Principles and Applications of Enviromagnetics*: Academic Press.
- Fey M., Korr C., Maidana N.I., Carrevedo M.L., Corbella H., Dietrich S., Haberzettl T., Kuhn G., Lücke A., Mayr C., Ohlendorf C., Paez M.M., Quintana F.A., Schäbitz F. & Zolitschka B. (2009): Palaeoenvironmental changes during the last 1600 years inferred from the sediment record of a cirque lake in southern Patagonia (Laguna Las Vizcachas, Argentina). *Palaeogeography, Palaeoclimatology, Palaeoecology* 281(3-4), 363-375.
- Forel F.A. (1879-1880): Contributions à l'étude de la limnimétrie de Lac Léman. *Bulletin de la Société Vaudoise des Sciences Naturelles* 16(83), 42-59.
- Forel F.A. (1885): Ravins sous-lacustre des fleuves glaciaires. *Bulletin de la Société vaudoise des ingénieurs et des architectes* 11, 53.
- Forel F.A. (1887): Le ravins sous-lacustre du Rhône dans le lac Léman. *Bulletin de la Société vaudoise des ingénieurs et des architectes* 23, 85-107.
- Franchini M. & Mannucci P.M. (2015): Impact on human health of climate changes. *European Journal of Internal Medicine* 26(1), 1-5.
- Gilbert G.K. (1890): Lake Bonneville. United States Geological Survey, Monograph 1.
- Haberzettl T., Fey M., Lücke A., Maidana N., Mayr C., Ohlendorf C., Schäbitz F., Schleser G.H., Wille M. & Zolitschka B. (2005): Climatically induced lake level changes during the last two millennia as reflected in sediments of Laguna Potrok Aike, southern Patagonia (Santa Cruz, Argentina). *Journal of Paleolimnology* 33(3), 283-302.
- Haberzettl T. (2006): Late Quaternary hydrological variability in southeastern Patagonia – 45,000 years of terrestrial evidence from Laguna Potrok Aike. (PhD-Thesis), University of Bremen, Bremen.
- Haberzettl T., Corbella H., Fey M., Janssen S., Lücke A., Mayr C., Ohlendorf C., Schäbitz F., Schleser G.H., Wille M., Wulf S. & Zolitschka B. (2007): Lateglacial and Holocene wet–dry cycles in southern Patagonia: chronology, sedimentology and geochemistry of a lacustrine record from Laguna Potrok Aike, Argentina. *The Holocene* 17(3), 297-310.
- Haberzettl T., Anselmetti F.S., Bowen S.W., Fey M., Mayr C., Zolitschka B., Ariztegui D., Mauz B., Ohlendorf C., Kastner S., Lücke A., Schäbitz F. & Wille M. (2009): Late Pleistocene dust deposition in the Patagonian steppe - extending and refining the paleoenvironmental and tephrochronological record from Laguna Potrok Aike back to 55 ka. *Quaternary Science Reviews* 28(25-26), 2927-2939.
- Haberzettl T., St-Onge G. & Lajeunesse P. (2010): Multi-proxy records of environmental changes in Hudson Bay and Strait since the final outburst flood of Lake Agassiz-Ojibway. *Marine Geology* 271(1-2), 93-105.
- Haberzettl T., St-Onge G., Behling H. & Kirleis W. (2013): Holocene radiocarbon-based chronologies by matching palaeomagnetic secular variations to geomagnetic field models: an example from Lake Kalimpa (Sulawesi, Indonesia). In: Jovane L., Herrero-Bervera E., Hinnov L.A. & Housen B.A. (Eds.), *Magnetic Methods and the Timing of Geological Processes*. London: Geological Society London Special Publications. pp. 245-259.
- Haberzettl T., Baade J., Compton J., Daut G., Dupont L., Finch J., Frenzel P., Green A., Hahn A., Hebbeln D., Helmschrot J., Humphries M., Kasper T., Kirsten K., Mäusbacher R., Meadows M., Meschner S., Quick L., Schefuß E., Wüdsch M. & Zabel M. (2014): Paleoenvironmental investigations using a combination of terrestrial and marine sediments from South Africa - The RAIN (Regional Archives for Integrated iNvestigations) approach. *Zentralblatt für Geologie und Paläontologie, Teil I*(1), 55-73.
- Haberzettl T., Henkel K., Kasper T., Ahlborn M., Su Y., Wang J., Appel E., St-Onge G., Stoner J., Daut G., Zhu L. & Mäusbacher R. (2015): Independently dated paleomagnetic secular variation records from the Tibetan Plateau. *Earth and Planetary Science Letters* 416, 98-108.
- Håkanson L. & Jansson M. (1983): *Principles of lake sedimentology*. Berlin: Springer.
- Hatfield R.G. & Stoner J.S. (2013): Magnetic Proxies and Susceptibility. In: Elias S.A. (Ed.), *Encyclopedia of Quaternary Science*: Elsevier. pp. 884–898.
- Holmgren K., Lee-Thorp J.A., Cooper G.R.J., Lundblad K., Partridge T.C., Scott L., Sithaldeen R., Siep Talma A. & Tyson P.D. (2003): Persistent millennial-scale climatic variability over the past 25,000 years in Southern Africa. *Quaternary Science Reviews* 22(21–22), 2311-2326.
- Hostetler S.W. (1995): Hydrological and Thermal Response of Lakes to Climate: Description and Modeling. In: Lerman A., Imboden D. & Gat J. (Eds.), *Physics and Chemistry of Lakes*: Springer Berlin Heidelberg. pp. 63-82.

- Hou J., Huang Y., Brodsky C., Alexandre M.R., McNichol A.P., King J.W., Hu F.S. & Shen J. (2010): Radiocarbon Dating of Individual Lignin Phenols: A New Approach for Establishing Chronology of Late Quaternary Lake Sediments. *Analytical Chemistry* 82(17), 7119-7126.
- Jones P.D. & Bradley R.S. (1995): Climatic variations in the longest instrumental records. In: Bradley R.S. & Jones P.D. (Eds.), *Climate since A.D. 1500*. London; New York: Routledge. pp. 706.
- Kasper T., Haberzettl T., Doberschütz S., Daut G., Wang J., Zhu L., Nowaczyk N. & Mäusbacher R. (2012): Indian Ocean Summer Monsoon (IOSM)-dynamics within the past 4 ka recorded in the sediments of Lake Nam Co, central Tibetan Plateau (China). *Quaternary Science Reviews* 39, 73-85.
- Kasper T., Frenzel P., Haberzettl T., Schwarz A., Daut G., Meschner S., Wang J., Zhu L. & Mäusbacher R. (2013): Interplay between redox conditions and hydrological changes in sediments from Lake Nam Co (Tibetan Plateau) during the past 4000 cal BP inferred from geochemical and micropaleontological analyses. *Palaeogeography, Palaeoclimatology, Palaeoecology* 392, 261-271.
- Kasper T., Haberzettl T., Wang J., Daut G., Doberschütz S., Zhu L. & Mäusbacher R. (2015): Hydrological variations on the Central Tibetan Plateau since the Last Glacial Maximum and their teleconnection to inter-regional and hemispheric climate variations. *Journal of Quaternary Science* 30(1), 70-78.
- Kastner S., Enters D., Ohlendorf C., Haberzettl T., Kuhn G., Lücke A., Mayr C., Reyss J.-L., Wastegård S. & Zolitschka B. (2010): Reconstructing 2000 years of hydrological variation derived from laminated proglacial sediments of Lago del Desierto at the eastern margin of the South Patagonian Ice Field, Argentina. *Global and Planetary Change* 72(3), 201-214.
- King J. & Peck J. (2001): Use of Paleomagnetism in Studies of Lake Sediments. In: Last W. & Smol J. (Eds.), *Tracking Environmental Change Using Lake Sediments* (Vol. 1): Springer Netherlands. pp. 371-389.
- Kirleis W., Pillar V. & Behling H. (2011): Human–environment interactions in mountain rainforests: archaeobotanical evidence from central Sulawesi, Indonesia. *Vegetation History and Archaeobotany* 20(3), 165-179.
- Korte M., Genevey A., Constable C.G., Frank U. & Schnepf E. (2005): Continuous geomagnetic field models for the past 7 millennia: 1. A new global data compilation. *Geochemistry, Geophysics, Geosystems* 6(2), Q02H15.
- Korte M., Donadini F. & Constable C.G. (2009): Geomagnetic field for 0–3 ka: 2. A new series of time-varying global models. *Geochemistry, Geophysics, Geosystems* 10(6), Q06008.
- Korte M. & Constable C. (2011): Improving geomagnetic field reconstructions for 0–3 ka. *Physics of the Earth and Planetary Interiors* 188(3-4), 247-259.
- Korte M., Constable C., Donadini F. & Holme R. (2011): Reconstructing the Holocene geomagnetic field. *Earth and Planetary Science Letters* 312(3-4), 497-505.
- Laj C., Kissel C., Scao V., Beer J., Thomas D.M., Guillou H., Muscheler R. & Wagner G. (2002): Geomagnetic intensity and inclination variations at Hawaii for the past 98 kyr from core SOH-4 (Big Island): a new study and a comparison with existing contemporary data. *Physics of the Earth and Planetary Interiors* 129(3-4), 205-243.
- Laj C. & Channell J.E.T. (2007): Geomagnetic Excursions. In: Schubert G. (Ed.), *Treatise on Geophysics*. Amsterdam: Elsevier. pp. 373-416.
- Last W.M. (2002): Geolimnology of salt lakes. *Geosciences Journal* 6(4), 347-369.
- Last W.M. & Ginn F.M. (2005): Saline systems of the Great Plains of western Canada: an overview of the limnogeology and paleolimnology. *Saline Systems* 1(10), doi:10.1186/1746-1448-1181-1110.
- Leemann A. & Niessen F. (1994): Holocene glacial activity and climatic variations in the Swiss Alps: reconstructing a continuous record from proglacial lake sediments. *The Holocene* 4(3), 259-268.
- Lisé-Pronovost A., St-Onge G., Gogorza C., Haberzettl T., Preda M., Kliem P., Francus P. & Zolitschka B. (2013): High-resolution paleomagnetic secular variations and relative paleointensity since the Late Pleistocene in southern South America. *Quaternary Science Reviews* 71, 91-108.
- Lisé-Pronovost A., St-Onge G., Gogorza C., Haberzettl T., Jouve G., Francus P., Ohlendorf C., Gebhardt C. & Zolitschka B. (2015): Rock-magnetic proxies of wind intensity and dust since 51,200 cal BP from lacustrine sediments of Laguna Potrok Aike, southeastern Patagonia. *Earth and Planetary Science Letters* 411, 72-86.
- Long H., Lai Z., Frenzel P., Fuchs M. & Haberzettl T. (2012): Holocene moist period recorded by the chronostratigraphy of a lake sedimentary sequence from Lake Tangra Yumco on the south Tibetan Plateau. *Quaternary Geochronology* 10, 136-142.

- Long H., Haberzettl T., Tsukamoto S., Shen J., Kasper T., Daut G., Zhu L., Mäusbacher R. & Frechen M. (2015): Luminescence dating of lacustrine sediments from Tangra Yumco (southern Tibetan Plateau) using post-IR IRSL signals from polymineral grains. *Boreas* 44(1), 139-152.
- Lougheed B.C., Nilsson A., Björck S., Snowball I. & Muscheler R. (2014): A deglacial palaeomagnetic master curve for Fennoscandia – Providing a dating template and supporting millennial-scale geomagnetic field patterns for the past 14 ka. *Quaternary Science Reviews* 106, 155-166.
- Lowe D.J. (2011): Tephrochronology and its application: A review. *Quaternary Geochronology* 6(2), 107-153.
- Lowrie W. (2007): Magnetostratigraphy. In: Gubbins D. & Herrero-Bervera E. (Eds.), *Encyclopedia of Geomagnetism and Paleomagnetism*: Springer Netherlands. pp. 664-670.
- Lund S., Stoner J.S., Channell J.E.T. & Acton G. (2006): A summary of Brunhes paleomagnetic field variability recorded in Ocean Drilling Program cores. *Physics of the Earth and Planetary Interiors* 156(3-4), 194-204.
- Lund S. (2007): Paleomagnetic secular variation. In: Gubbins D. & Herrero-Bervera E. (Eds.), *Encyclopedia of Geomagnetism and Paleomagnetism*: Springer Netherlands. pp. 766-776.
- Mackereth F.J.H. (1971): On the variation in direction of the horizontal component of remanent magnetisation in lake sediments. *Earth and Planetary Science Letters* 12(3), 332-338.
- Maher B. (2007): Environmental magnetism. In: Gubbins D. & Herrero-Bervera E. (Eds.), *Encyclopedia of Geomagnetism and Paleomagnetism*: Springer Netherlands. pp. 248-256.
- Masson-Delmotte V., Schulz M., Abe-Ouchi A., Beer J., Ganopolski A., Rouco J.F.G., Jansen E., Lambeck K., Luterbacher J., Naish T., Osborn T., Otto-Bliesner B., Quinn T., Ramesh R., Rojas M., Shao X. & Timmermann A. (2013): Information from Paleoclimate Archives. In: Stocker T.F., Qin D., Plattner G.-K., Tignor M., Allen S.K., Boschung J., Nauels A., Xia Y., Bex V. & Midgley P.M. (Eds.), *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.
- Mazaud A., Sicre M.A., Ezat U., Pichon J.J., Duprat J., Laj C., Kissel C., Beaufort L., Michel E. & Turon J.L. (2002): Geomagnetic-assisted stratigraphy and sea surface temperature changes in core MD94-103 (Southern Indian Ocean): possible implications for North–South climatic relationships around H4. *Earth and Planetary Science Letters* 201(1), 159-170.
- McManus J., Oppo D., Cullen J. & Healey S. (2013): Marine Isotope Stage 11 (Mis 11): Analog for Holocene and Future Climate? In: Droxler A.W., Poore R.Z. & Burckle L.H. (Eds.), *Earth's Climate and Orbital Eccentricity: The Marine Isotope Stage 11 Question: American Geophysical Union*. pp. 69-85.
- Meadows M.E. (2001): The role of Quaternary environmental change in the evolution of landscapes: case studies from southern Africa. *CATENA* 42(1), 39-57.
- Merrill R.T. & McFadden P.L. (2007): Paleomagnetism. In: Gubbins D. & Herrero-Bervera E. (Eds.), *Encyclopedia of Geomagnetism and Paleomagnetism*: Springer Netherlands. pp. 776-780.
- Meybeck M. (1995): Global Distribution of Lakes. In: Lerman A., Imboden D. & Gat J. (Eds.), *Physics and Chemistry of Lakes*: Springer Berlin Heidelberg. pp. 1-35.
- Miehe S., Miehe G., van Leeuwen J.N., Wrožyna C., van der Knaap W., Duo L. & Haberzettl T. (2014): Persistence of Artemisia steppe in the Tangra Yumco Basin, west-central Tibet, China: despite or in consequence of Holocene lake-level changes? *Journal of Paleolimnology* 51(2), 267-285.
- Niemann H., Haberzettl T. & Behling H. (2009): Holocene climate variability and vegetation dynamics inferred from the (11700 cal. yr BP) Laguna Rabadilla de Vaca sediment record, southeastern Ecuadorian Andes. *The Holocene* 19(2), 307-316.
- Nilsson A., Holme R., Korte M., Suttie N. & Hill M. (2014): Reconstructing Holocene geomagnetic field variation: new methods, models and implications. *Geophysical Journal International*, doi: 10.1093/gji/ggu1120.
- Nowaczyk N.R. & Knies J. (2000): Magnetostratigraphic results from the eastern Arctic Ocean: AMS ¹⁴C ages and relative palaeointensity data of the Mono Lake and Laschamp geomagnetic reversal excursions. *Geophysical Journal International* 140(1), 185-197.
- Nowaczyk N.R., Antonow M., Knies J. & Spielhagen R.F. (2003): Further rock magnetic and chronostratigraphic results on reversal excursions during the last 50 ka as derived from northern high latitudes and discrepancies in precise AMS ¹⁴C dating. *Geophysical Journal International* 155(3), 1065-1080.
- Ohlendorf C., Fey M., Gebhardt C., Haberzettl T., Lücke A., Mayr C., Schäbitz F., Wille M. & Zolitschka B. (2013): Mechanisms of lake-level change at Laguna Potrok Aike (Argentina) – insights from hydrological balance calculations. *Quaternary Science Reviews* 71, 27-45.

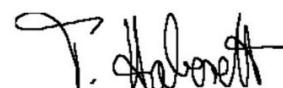
- Ohlendorf C., Fey M., Massafiero J., Haberzettl T., Laprida C., Lücke A., Maidana N., Mayr C., Oehlerich M., Ramón Mercau J., Wille M., Corbella H., St-Onge G., Schäbitz F. & Zolitschka B. (2014): Late Holocene hydrology inferred from lacustrine sediments of Laguna Cháltel (southeastern Argentina). *Palaeogeography, Palaeoclimatology, Palaeoecology* 411, 229-248.
- Oldfield F. & Richardson N. (1990): Peats and lake sediments: formation, stratigraphy, description and nomenclature. In: Goudie A., Anderson M., Burt T., Lewin J., Richards K., Whalley B. & Worsley P. (Eds.), *Geomorphological Techniques* (2nd ed.). London; Boston: Unwin Hyman. pp. 428-455.
- Opdyke N.D. & Channell J.E.T. (1996): *Magnetic stratigraphy*. San Diego: Academic Press.
- Peck J.A., King J.W., Colman S.M. & Kravchinsky V.A. (1996): An 84-kyr paleomagnetic record from the sediments of Lake Baikal, Siberia. *Journal of Geophysical Research: Solid Earth* 101(B5), 11365-11385.
- Pugh R.S., McCave I.N., Hillenbrand C.D. & Kuhn G. (2009): Circum-Antarctic age modelling of Quaternary marine cores under the Antarctic Circumpolar Current: Ice-core dust-magnetic correlation. *Earth and Planetary Science Letters* 284(1-2), 113-123.
- Reeves C.C. (1968): *Introduction to paleolimnology*. Amsterdam, New York; Elsevier Pub. Co.
- Reinwarth B., Franz S., Baade J., Haberzettl T., Kasper T., Daut G., Helmschrot J., Kirsten K.L., Quick L.J., Meadows M.E. & Mäusbacher R. (2013): A 700-year record on the effects of climate and human impact on the southern Cape coast inferred from lake sediments of Eilandvlei, Wilderness Embayment, South Africa. *Geografiska Annaler: Series A, Physical Geography* 95(4), 345-360.
- Roberts A.P. (2007): Environmental magnetism, paleomagnetic applications. In: Gubbins D. & Herrero-Bervera E. (Eds.), *Encyclopedia of Geomagnetism and Paleomagnetism*: Springer Netherlands. pp. 256-261.
- Roberts A.P. (2008): Geomagnetic excursions: Knowns and unknowns. *Geophysical Research Letters* 35(17), L17307.
- Roberts A.P. & Turner G.M. (2013): Geomagnetic Excursions and Secular Variations. In: Elias S.A. (Ed.), *The Encyclopedia of Quaternary Science* (Vol. 1). Amsterdam: Elsevier. pp. 705-720.
- Rousseau D.-D. (2013): The Continental Record of Stage 11: a Review. In: Droxler A.W., Poore R.Z. & Burckle L.H. (Eds.), *Earth's Climate and Orbital Eccentricity: The Marine Isotope Stage 11 Question*: American Geophysical Union. pp. 213-222.
- Russel I.C. (1885): *Geological History of Lake Lahontan, A Quaternary Lake of Northwestern Nevada*. United States Geological Survey Monograph 11.
- Sagnotti L., Scardia G., Giaccio B., Liddicoat J.C., Nomade S., Renne P.R. & Sprain C.J. (2014): Extremely rapid directional change during Matuyama-Brunhes geomagnetic polarity reversal. *Geophysical Journal International* 199(2), 1110-1124.
- Salis A.v. (1884): *Hydrotechnische Notizen*. Schweizerische Bauzeitung 3/4(22), 127.
- Schewe J., Heinke J., Gerten D., Haddeland I., Arnell N.W., Clark D.B., Dankers R., Eisner S., Fekete B.M., Colón-González F.J., Gosling S.N., Kim H., Liu X., Masaki Y., Portmann F.T., Satoh Y., Stacke T., Tang Q., Wada Y., Wisser D., Albrecht T., Frieler K., Piontek F., Warszawski L. & Kabat P. (2014): Multimodel assessment of water scarcity under climate change. *Proceedings of the National Academy of Sciences* 111(9), 3245-3250.
- Scholze M., Knorr W., Arnell N.W. & Prentice I.C. (2006): A climate-change risk analysis for world ecosystems. *Proceedings of the National Academy of Sciences* 103(35), 13116-13120.
- Singer B. (2007): Polarity Transitions: Radioisotopic Dating. In: Gubbins D. & Herrero-Bervera E. (Eds.), *Encyclopedia of Geomagnetism and Paleomagnetism*: Springer Netherlands. pp. 834-839.
- Singer B. (2014): A Quaternary geomagnetic instability time scale. *Quaternary Geochronology* 21, 29-52.
- Singer B.S., Guillou H., Jicha B.R., Laj C., Kissel C., Beard B.L. & Johnson C.M. (2009): $^{40}\text{Ar}/^{39}\text{Ar}$, K–Ar and ^{230}Th – ^{238}U dating of the Laschamp excursion: A radioisotopic tie-point for ice core and climate chronologies. *Earth and Planetary Science Letters* 286(1-2), 80-88.
- Smol J.P. (2008): *Pollution of lakes and rivers: a paleoenvironmental perspective*. Malden, MA: Blackwell Pub.
- Snowball I., Zillén L., Ojala A., Saarinen T. & Sandgren P. (2007): FENNOSTACK and FENNORPIS: Varve dated Holocene palaeomagnetic secular variation and relative palaeointensity stacks for Fennoscandia. *Earth and Planetary Science Letters* 255(1-2), 106-116.
- Spiess V., Daut G., Wenau S., Gernhardt F., Wang J., Schwenk T., Haberzettl T., Zhu L. & Mäusbacher R. (2014). Lake Nam Co (Tibet, China) - a suitable target for a deep drilling project as confirmed by a preliminary airgun seismic survey. Paper presented at the 2014 AGU Fall Meeting, San Francisco. <https://agu.confex.com/agu/fm14/meetingapp.cgi#Paper/28838>

- Stocker T.F., Qin D., Plattner G.-K., Alexander L.V., Allen S.K., Bindoff N.L., Bréon F.-M., Church J.A., Cubasch U., Emori S., Forster P., Friedlingstein P., Gillett N., Gregory J.M., Hartmann D.L., Jansen E., Kirtman B., Knutti R., Kumar K.K., Lemke P., Marotzke J., Masson-Delmotte V., Meehl G.A., Mokhov I.I., Piao S., V. Ramaswamy D., Randall, Rhein M., Rojas M., Sabine C., Shindell D., Talley L.D., Vaughan D.G. & Xie S.-P. (2013): Technical Summary. In: Stocker T.F., Qin D., Plattner G.-K., Tignor M., Allen S.K., Boschung J., Nauels A., Xia Y., Bex V. & Midgley P.M. (Eds.), *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.
- Stockhausen H. (1998): Geomagnetic palaeosecular variation (0–13 000 yr BP) as recorded in sediments from three maar lakes from the West Eifel (Germany). *Geophysical Journal International* 135(3), 898-910.
- Stoner J.S. & St-Onge G. (2007): Chapter Three: Magnetic Stratigraphy in Paleoceanography: Reversals, Excursions, Paleointensity, and Secular Variation. In: Stein R., Blackman D.K., Inagaki F. & Larsen H.-C. (Eds.), *Developments in Marine Geology* (Vol. 1): Elsevier. pp. 99-138.
- Talbot M.R. & Allen P.A. (1996): Lakes. In: Reading H.G. (Ed.), *Sedimentary Environments: Processes, Facies, and Stratigraphy*. Oxford: Blackwell Science. pp. 83-124.
- Tauxe L. (1993): Sedimentary records of relative paleointensity of the geomagnetic field: Theory and practice. *Reviews of Geophysics* 31(3), 319-354.
- Teanby N., Laj C., Gubbins D. & Pringle M. (2002): A detailed palaeointensity and inclination record from drill core SOH1 on Hawaii. *Physics of the Earth and Planetary Interiors* 131(2), 101-140.
- Thompson R., Battarbee R.W., O'Sullivan P.E. & Oldfield F. (1975): Magnetic susceptibility of lake sediments. *Limnology & Oceanography* 20(5), 687-698.
- Thompson R. (1986): Palaeomagnetic dating. In: Berglund B.E. (Ed.), *Handbook of holocene palaeoecology and palaeohydrology*. Chichester: Wiley. pp. 313-327.
- Turner G.M. & Thompson R. (1981): Lake sediment record of the geomagnetic secular variation in Britain during Holocene times. *Geophysical Journal of the Royal Astronomical Society* 65(3), 703-725.
- Verrecchia E.P. (2008): Lacustrine and Palustrine Geochemical Sediments. In: Nash D.J. & McLaren S.J. (Eds.), *Geochemical Sediments and Landscapes*: Blackwell Publishing Ltd. pp. 298-329.
- Wagner G.A. (1998): Age determination of young rocks and artifacts physical and chemical clocks in quaternary geology and archaeology. Berlin: Springer.
- Warszawski L., Friend A., Ostberg S., Frieler K., Lucht W., Schaphoff S., Beerling D., Cadule P., Ciais P., Clark D.B., Kahana R., Ito A., Keribin R., Kleidon A., Lomas M., Nishina K., Pavlick R., Rademacher T.T., Buechner M., Piontek F., Schewe J., Serdeczny O. & Schellnhuber H.J. (2013): A multi-model analysis of risk of ecosystem shifts under climate change. *Environmental Research Letters* 8(4), 044018.
- Weber M.E., Kuhn G., Spreng D., Rolf C., Ohlwein C. & Ricken W. (2012): Dust transport from Patagonia to Antarctica - A new stratigraphic approach from the Scotia Sea and its implications for the last glacial cycle. *Quaternary Science Reviews* 36, 177-188.
- Wüdsch M., Biagioni S., Behling H., Reinwarth B., Franz S., Bierbaß P., Daut G., Mäusbacher R. & Haberzettl T. (2014): ENSO and monsoon variability during the past 1.5 kyr as reflected in sediments from Lake Kalimpa, Central Sulawesi (Indonesia). *The Holocene* 24(12), 1743-1756.
- Yu Y., Doh S.-J., Kim W., Park Y.-H., Lee H.-J., Yim Y., Cho S.-G., Oh Y.-S., Lee D.-S., Lee H.-H., Gong M.-G., Hyun D.-H., Cho J.-K., Sin Y.-S. & Do M.-S. (2010): Archeomagnetic secular variation from Korea: Implication for the occurrence of global archeomagnetic jerks. *Earth and Planetary Science Letters* 294(1-2), 173-181.
- Zheng Y., Zheng H., Deng C. & Liu Q. (2014): Holocene paleomagnetic secular variation from East China Sea and a PSV stack of East Asia. *Physics of the Earth and Planetary Interiors* 236, 69-78.
- Zhu D., Meng X., Zhao X., Shao Z., Xu Z., Yang C., Ma Z., Wu Z., Wu Z. & Wang J. (2004): Evolution of an Ancient Large Lake in the Southeast of the Northern Tibetan Plateau. *Acta Geologica Sinica - English Edition* 78(4), 982-992.
- Zolitschka B., Schäbitz F., Lücke A., Corbella H., Ercolano B., Fey M., Haberzettl T., Janssen S., Maidana N., Mayr C., Ohlendorf C., Oliva G., Paez M.M., Schleser G.H., Soto J., Tiberi P. & Wille M. (2006): Crater lakes of the Pali Aike Volcanic Field as key sites for paleoclimatic and paleoecological reconstructions in southern Patagonia, Argentina. *Journal of South American Earth Sciences* 21(3), 294-309.

Torsten Haberzettl

Physical Geography, Institute of Geography, Friedrich-Schiller-University Jena,
Löbdergraben 32, 07743 Jena, Germany
Phone: +49 (0) 3641-948815, Fax: +49 (0) 3641-948812
torsten.haberzettl@uni-jena.de
<http://www.geographie.uni-jena.de/Haberzettl>

- Since February 2010: **Research Associate – Friedrich-Schiller-University Jena** (Germany)
Institute of Geography,
Physical Geography
- Since 2010: **DOSECC** (Drilling, Observation and Sampling of the Earth's Continental Crust)
Science Planning Committee (USA)
- 06/2014-08/2014: **Visiting Researcher – Oregon State University** (Corvallis, USA)
College of Earth, Ocean, and Atmospheric Sciences,
Paleomagnetic & Environmental Magnetic Research Laboratory
- 08/2008-11/2009: **Post-Doctoral Researcher – University of Québec at Rimouski** (Canada)
Institut des sciences de la mer de Rimouski (ISMER, Canada)
Canada Research Chair in Marine Geology,
Sedimentary Paleomagnetism and Marine Geology Laboratory
- 08/2008-11/2009: **Member of GEOTOP Research Center** (Québec, Canada)
- 10/2006-07/2008: **Research Associate – University of Göttingen** (Germany)
Geoscience Center Göttingen,
Sedimentology and Environmental Geology
- July 2006: **PhD** (Dr. rer. nat.) – **University of Bremen** (Germany)
Dissertation: *Late Quaternary hydrological variability in southeastern Patagonia – 45,000 years of terrestrial evidence from Laguna Potrok Aike*
- 04/2002-09/2006: **Research Associate – University of Bremen** (Germany)
Institute of Geography,
GEOPOLAR (Geomorphology and Polar Research)
- February 2002: **Diplom** (Geography) – **University of Bamberg** (Germany)
Thesis: *Holocene environmental history and human impact on subrosion depressions in a Lower Franconian (Germany) 'Gäu'-area – title translated*
- 1999-2002: **Research Assistant – University of Bamberg** (Germany)
Chair of Physical Geography and Chair of Archaeology
- 1998-2002: **Geography studies (Diplom) – University of Bamberg** (Germany)



Ehrenwörtliche Erklärung

Ich erkläre hiermit, dass mir die Habilitationsordnung der Friedrich-Schiller-Universität Jena bekannt ist.

Ferner erkläre ich, dass ich die vorliegende Arbeit ohne unzulässige Hilfe Dritter und ohne Benutzung anderer als der angegebenen Hilfsmittel angefertigt habe. Die aus anderen Quellen direkt oder indirekt übernommenen Daten und Konzepte sind unter Angabe der Quelle gekennzeichnet.

Bei der Auswahl und Auswertung folgenden Materials haben mir die nachstehend aufgeführten Personen in der jeweils beschriebenen Weise entgeltlich/unentgeltlich geholfen:

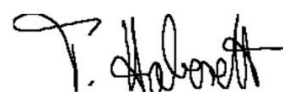
Siehe Co-Autoren der einzelnen Manuskripte

Weitere Personen waren an der inhaltlich-materiellen Erstellung der Arbeit nicht beteiligt. Insbesondere habe ich hierfür nicht die entgeltliche Hilfe von Vermittlungs- bzw. Beratungsdiensten in Anspruch genommen. Niemand hat von mir unmittelbar oder mittelbar geldwerte Leistungen für Arbeiten erhalten, die im Zusammenhang mit dem Inhalt der vorgelegten Arbeit stehen.

Die Arbeit wurde bisher weder im In- noch Ausland in gleicher oder ähnlicher Form einer anderen Prüfungsbehörde vorgelegt.

Ich versichere, dass ich nach bestem Wissen die reine Wahrheit gesagt und nichts verschwiegen habe.

Jena, den 29. Mai 2015



Unterschrift